Precise positioning services in the rail sector

An estimate of the economic and social benefits of augmented positioning services in the rail sector

Prepared for the Department of Innovation, Industry, Climate Change Science, Research and Tertiary Education

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Executive summary

Augmented GNSS in the rail sector currently has applications in surveying track, locating infrastructure, managing train movements (mainly in long distance applications) and in management of rail operations at ports.

It is increasingly being used in track surveying and location of infrastructure which requires precision of around 2 cm accuracy. This applies to all sectors – long distance, mining and metropolitan systems.

There is potential for precise GNSS to be used in Automated Train Management Systems (ATMS) that require accurate and reliable positioning systems to identify the leading and trailing edge of trains and relay its position to a central train control systems.

Current systems use track circuits to determine whether a train is on a section of track (between two signals), but do not locate where the train is on that section. More precise location information is relayed verbally by the driver to train control.

Automated Train Management Systems (ATMS) can replace track side signalling with in cab displays to provide precise location of trains, to support digital network control centres and other train control mechanisms for use by both drivers and controllers. The advantage of ATMS is that it can increase rail capacity through closer train operations, improved reliability, efficiency and flexibility and increased safety through better management of speed limits.

Accurate and reliable positioning from augmented GNSS could also facilitate the opening up of further value-adding services, such as driverless trains, advanced forms of train protection and control, improved maintenance and track monitoring.

ATMS is likely to find application in long distance systems but metropolitan systems are more likely to adopt European Train Control Systems (ETCS) that depend on track transponders rather than GNSS systems.

ACIL Tasman has estimated the likely productivity benefits and savings from the use of precise GNSS for track surveying and management and the future use of ATMS by the Australian Rail Track Corporation and in 2020 by the dedicated mine rail systems:

- accumulated benefits of between $1.8 million and $3.4 million (0.02 per cent and 0.03 per cent of the value of production in the sector) in 2012 attributable to lower costs and improved productivity in the use of precise GNSS in surveying track and rail infrastructure.
- benefits rise to between $9.5 million and $10.1 million (around 0.08 per cent of the value of production in the sector) by 2020 based on installation of ATMS on ARTC lines by 2020.

The impact on the economy would be reduced operating costs for freight railways (both train operations and signal maintenance), a deferral of the cost of investing in capacity enhancements, more competitive rail freight (hence a shift from road freight) and flow-on benefits to the wider economy through lower freight rates.

The high case would require wider coverage of GNSS augmentation across Australia and compatibility between different augmentation systems available to the rail sector.

Modelling indicated that the use of augmented GNSS had not had a significant impact on output from the sector in 2012. However output could be up to $12 million higher by 2020 on the above assumptions.

These results could be higher if metropolitan systems adopted ATMS systems. However to utilise augmented GNSS, there would need to be further development of localised GNSS compatible positioning systems for use in tunnels. There is no technology currently available to do this task.

Key findings

- The most common use of augmented GNSS in the rail sector to date has been in track and signal placement and for automated train management systems for long distance rail.
- There is potential for precise GNSS to support Automatic Train Management Systems. The Australian Rail Track Corporation (ARTC) is investigating the use of such systems for its longer distance track infrastructure and systems. The metropolitan rail systems have however adopted the European Train Control Systems (ETCS) which relies on in track transponders and do not use precise GNSS for positioning.
- High resolution GNSS is needed for automated stevedoring at ports and, after significant hurdles are overcome, might be deployed in rail terminals with a similar gain to efficiency.
- Positioning technology is being developed for automatic train management, which will allow wayside signals to largely be replaced by in-cab signalling. Most of this (outside metropolitan areas) will require augmented GNSS for integrity monitoring and reliability criteria.
- Allowing trains to be safely operated closer together would have system wide capacity benefits. Such developments are still some way off in the Australian rail sector.

1 Introduction

ACIL Allen Consulting, in partnership with SKM and Lester Franks Surveyors and Planners, has been commissioned by the Department of Industry, Innovation, Climate Change, Science, Research and Tertiary Education to assess the value of augmented positioning services in Australia.

The purpose of this report is to provide an understanding of the economic and social benefits of precise positioning information within the rail sector. This information is to allow better informed decision-making and assist in identifying areas for growth and investment from both the private sector and government. It will also provide context to the National Positioning Infrastructure Plan being developed by Geoscience Australia.

2 The rail sector

The rail industry has at least three distinct sectors: bulk freight (ores, minerals and grains), non-bulk and break-bulk freight (containerised goods, non-containerised manufactured goods), and passenger transport (mainly urban and regional).

The rail sector is characterised by long lived investments. Many locomotives are 20-30 years old; wagons are typically used for 30-40 years. Signalling systems are maintained for 20-50 years. Investments in new track can be expected to last for at least 50 years if adequately maintained. This has implications for its take up of new technologies.

Within Australia, rail dominates mineral freight and non-bulk (container type) freight between the east and west coast. It struggles elsewhere with a low market share for non-bulk freight on the east coast, low returns on grain freight, and with large subsidies on urban services.

Productivity improvements would lower costs and allow rail services to better compete with cars and trucks.

2.1.1 Common themes

Non-augmented GNSS is a valuable tool used by both track managers and train operators. GNSS applications in rail have helped to improve asset management, the efficiency of asset use and provide improved customer services by tracking trains. These uses generally do not require high resolution positioning.

Precise GNSS currently has applications in surveying track, locating infrastructure, managing train movements mainly in long distance applications and in management of rail operations at Ports.

Accurate and reliable GNSS could facilitate the opening up of further value-adding services, such as driverless trains, advanced forms of train protection and control, improved maintenance and track monitoring. However the existence of significant legacy investments combined with cost has resulted in alternative approaches to precise GNSS in most urban rail systems.

A lack of precision and reliability in GNSS positioning in the past has led to the development of alternative or parallel technologies to establish train position. Any positioning system needs to be robust to trains passing through tunnels, areas of sparse coverage (such as the Nullarbor desert) and possible interference from overhead electrical cables or proximate steel surfaces.

At present the main use of augmented, high resolution, positioning in the rail industry is surveying of track. Modern train management requires accurate maps of the railway (centre line, curvature and gradient), and location of signalling infrastructure. Positioning of track is typically required to be accurate within a few centimetres. Historical maps of asset locations are not sufficiently accurate for some modern applications and so an exercise of remapping (and recording new track placements) is underway in many states.

Augmented GPS allows for much more accurate maps to be drawn and recorded with less effort than previous methods including traditional surveying.

2.1.2 Bulk freight

Bulk freight comprises ores, minerals and grains over short to medium distances from mines to ports or from grain silos to ports. The goods are characterised by homogeneity of the products in each wagon (different grades of ores, minerals and grains exist but are segregated).

In the case of ores and minerals, this freight sometimes moves on dedicated track owned by the mines, and sometimes moves on shared track managed by State track authorities or Australian Rail Track Corporation (ARTC).

In bulk freight applications the main use of augmented, high resolution, positioning is in surveying of track. Accuracy of around 2 cm is required as in most surveying activities.

There are many other applications of lower resolution GNSS, including:

- locating locomotives and ensuring appropriate asset utilisation as a result
- cost savings from driverless trains in remote areas (e.g. Pilbara).
- optimised driving, which adjusts acceleration to take advantage of topography and requires positioning to identify when to accelerate/brake and what the optimal speed is for minimum fuel consumption.

While there is potential to use augmented GNSS for control and train management in the future, progress is expected to be relatively slow in following up these applications. The case study of the use of GNSS by Rio

Tinto in its Pilbara operations shows that most of the uses of GNSS, such as driver and train monitoring, do not currently require more precise GNSS measurement. However monitoring of train movements in railway yards and in tunnels does require augmentation because of signal bounce and interference. Augmented GNSS has the potential to address such problems and may play a greater role in the future.

2.1.3 Non-bulk and break bulk freight

Non-bulk and break bulk freight on rail typically relates to inter-capital movements of manufactured goods on intermodal services. That is, goods which move by truck to a terminal, are then loaded on to a train, move by train on the 'line haul' between cities, are unloaded at a receiving terminal before being picked up by truck and delivered to the customer.

Intermodal services offer an alternative to road transport between cities. Intercity freight movements mostly occur on track owned and managed by Australian Rail Track Corporation (ARTC), a government owned entity. Movements between Tarcoola and Darwin take place on a railway owned and managed by Genesee and Wyoming Australia. Track between Kalgoorlie and Perth, and in Sydney, is leased to ARTC.

Augmented GNSS is currently used by ARTC for surveying the track. The major impetus for this is the intended roll-out of ARTC's Automated Train Management System (ATMS), which is a form of advanced train protection and control which will also yield capacity benefits and reduced infrastructure costs[1]. High resolution GNSS creates efficiencies in this surveying task by reducing the time and labour required in setting out and measuring coordinates. It also provides the opportunity for more efficient data capture and transmission to central data bases and can where necessary be used with remote sensing technologies to monitor and in some cases control systems..….

Other GNSS uses by ARTC include:

- locating signalling assets
- locating maintenance issues on track, as recorded by specialised maintenance vehicles.

Logistics value-add in conjunction with rail operations

Train operators offer services between cities and sometimes incorporate other value-added services such as freight planning, warehousing and tertiary (to customer) delivery.

The dominant train operator is Asciano. As well as Asciano, train operators include the newly-privatised Queensland Rail National (now called Aurizon), and Specialised Container Transport (SCT). The case study of the use of

[1] ATMS is one of the case studies detailed below.

precise GNSS by Asciono (see Section A.3 in Appendix A) shows that there is a significant demand for millimetre accuracy in port operations such as those at Botany.

Lack of augmented GNSS in the past has resulted in this positioning in container terminals being supplied by GNSS augmented by radar positioning. Had high-precision GNSS been available ten years ago perhaps this would be the sole positioning system in use.

GNSS is used by the train operators for:

- asset location and monitoring
- fuel economy software which calculates the optimum driving profile for the journey, to reduce the need for acceleration and subsequent (wasteful) braking
- monitoring the efficiency of train loading by monitoring the path of fork lift trucks
- monitoring the progress of trains within track segments
- recording of journey progress for customer tracking
- recording the location of incidents that cause delays or where potential maintenance is required
- GNSS triggers of important events, such as shift changes, required on-train activities or procedures.

In most cases however, accuracy is only required to 100 metre accuracy which can be supplied with stand-alone GNSS. However augmented GNSS could be valuable in the future for managing and monitoring train movements in shunting yards and in tunnels where stand-alone GNSS is either unreliable or unavailable.

2.1.4 Passenger rail

Urban passenger railways rely heavily on long established existing signalling systems and safe working systems. The location of trains is identified via track circuits and signalling equipment.

These technologies were all established before GNSS was a commercial reality, and if they were to be replaced it would be likely that augmented GNSS could cost effectively fulfil a number of these functions. The most likely system to be followed in Australia is a European one based on transponders whereas the ARTC system will be augmented GNSS-based. European Train Control Systems (ETCS) were developed before the availability of GNSS and have not embraced augmented GNSS at this point in time.

Similar to rail freight operations, RailCorp (soon to be split into NSW Trains and Sydney Trains) is currently using high resolution positioning to survey its existing track before deploying advanced train protection systems. Other capital city railways are likely to need to undertake this level of precise surveying prior to their investments in advanced train protection and control systems.

3 Productivity impacts

For this study, ACIL Allen used case studies of applications in the rail industry in Australia to provide data on the productivity impacts of specific applications. Levels of adoption of these applications were then used to estimate likely national benefits for 2012 and potentially for 2020.

Four case studies were selected for the rail industry. These were:

1. Automated Train Management System (ARTC)
2. Fuel saving technologies (Asciano/all train operators/bulk haulers)
3. More efficient surveying in anticipation of European Train Control Systems (RailCorp)
4. Improving the efficiency of asset use (Rio Tinto/Asciano).

The first of these promises significant productivity improvements and is discussed in this paper. The others offer lower productivity benefits, and the third is out of scope because it uses older signalling infrastructure and track circuits does not involve augmented GNSS although it does indicate potential benefits if augmented GNSS were to become more cost competitive. The case studies are covered in Appendix A.

3.1 Australian Rail Track Corporation (ARTC)

ARTC is the track manager for the interstate track between Perth (leased from Kalgoorlie-Perth), Adelaide, Melbourne, Sydney (leased on the South Sydney Freight Line), and Brisbane.

ARTC has invested considerable time and money into developing Automated Train Management System (ATMS) which uses augmented GNSS to identify the front and back of a train, and frequently relay its position to a central train control system.

Current systems use track circuits to determine whether a train is on a section of track (between two signals), but do not locate where the train is on that section. More precise location information is relayed verbally by the driver to train control. Typically only one train is allowed on a track section at a time, and the presence of the train turns the signal behind it red.

Once operational, ATMS will:

- replace trackside signalling with in-cab displays of movement authorities to drivers
- provide precise location of trains both front and rear

- provide new digital network control centres, each capable of controlling all traffic on the ARTC national network
- provide a backup capability in the event of failure at one control centre
- provide enforcement of override controls on each locomotive if a train is at risk of exceeding its authority to move forward on a certain track segment
- provide switch settings and automatic route clearances
- provide information (voice and data) to all locomotives via the Telstra 3G National Network.

The advantages of ATMS are that the position of the train is known within a few metres, and other information such as time, velocity and train health can be relayed with this information. Once the concept has been proved and safety accredited the advantages of ATMS will be:

- increased rail capacity through closer train operation
- improved reliability through better on-time performance
- improved efficiency and flexibility of the rail network
- increased safety through authority and speed limit enforcement
- additional protection for trackside workers
- operator savings through less fuel consumption, less wear of wheels and brakes, and fewer train crew hours
- reduced operation and maintenance cost for the trackside infrastructure.

ATMS was trialled on a section of track between Crystal Brook to Port Pirie and Stirling North.

In advance of trains running on these sections (some 100 kilometres of test-route) the track was surveyed to within 2 centimetres positional accuracy. The surveying of track is time consuming and expensive – ARTC manages some 11,000 kilometres of track around Australia and would benefit from cost efficiencies in surveying the track using high resolution GNSS.

3.1.1 ATMS and GNSS

The ATMS equipment uses GNSS which locates the front and end of the train within 2 metres accuracy (interstate freight trains are 1200 to 1800 metres long). Trains must pass through the Nullarbor and also through tunnels and all GNSS must be extremely reliable. Because of the absence of reliable and cost effective high resolution GNSS coverage of the ARTC network the ATMS locational systems use both GNSS and inertial monitoring systems (such as tachometers) to determine position on the track.

If ARTC could rely on augmented GNSS alone (and this would need to be extremely reliable) then perhaps ATMS set-top boxes would need less equipment and therefore less equipment to integrate with train systems, which would save money per box and per train. ARTC was unable to make an estimate of what this cost saving might be.

3.1.2 ATMS implementation costs and benefits

The current cost of on-board equipment is some $100,000 per locomotive; this includes location equipment as well as the computer which interprets the train authorities, velocity, position, and other information.

This would need to be installed on about 700 locomotives for the interstate freight task. ATMS on-board equipment could also be installed on regional train services, metropolitan rail services and maintenance equipment (e.g., high rail vehicles, grinders, etc.), but this is less likely because of the lower capital value of maintenance vehicles.

There would be ATMS installation costs (integrating the locomotive braking systems and inertial information to the ATMS interface) which are significant, but not yet known to ARTC.

If the GNSS signal is lost, trains can run without using ATMS, but the distance between trains is lengthened and instructions are verbally transmitted to drivers. This reduces the capacity of the railway, increases journey times for goods, and is less safe.

ATMS could double ARTC's track capacity

ATMS's ability to increase capacity and defer capital expenditure on track is significant. The network is 10,000-11,000 kilometres long. The cost to double capacity would be between $10-20 billion, estimates of $1m per kilometre are not unreasonable. **ATMS would be able to more than double ARTC's track capacity, it would allow trains to run with 4 minute headways (time between trains) – this is 3-6 times the current operating capacity of the railway.**

Avoiding track duplication has externality benefits too, since duplicating track in urban environments brings track closer to houses, with increased noise and pollution costs.

Augmented GNSS could provide accurate time stamping to control centres

Accurate time stamps for GNSS data are important because messages to the train control centre are time stamped with the GNSS time. This is particularly useful if a train is involved in an incident or reporting an incident. It is also useful for monitoring progress to the schedule. The higher reliability of augmented GNSS would be an advantage here but it is not always considered necessary in the industry for these purposes.

3.1.3 Other GNSS uses at ARTC

Maintenance vehicles journey along the track recording the location of worn or faulty track. Accurate recording would be beneficial, but not essential. Maintenance crews can locate the issue if provided with coordinates accurate within a few metres.

3.1.4 Conclusion

High resolution GPS would reduce costs in surveying track and it could lead to a reduction in the cost of on-board ATMS equipment. GPS based ATMS would have significant productivity benefits:

- improvements in capacity,
- flexibility
- safety
- reliability
- costs.

For these applications reliability is more important than accuracy. If a train system is to depend on GNSS signals it must be confident that the signal is correct at all times. As in all transport monitoring and navigation, system failures can have disastrous consequences. High reliability and integrity monitoring is therefore important.

3.2 Level of adoption

Precise positioning using augmented positioning is currently in use for surveying the railways, and will continue for at least 10 years (an estimate of the time to survey all existing track around Australia). Major surveying exercises are currently underway in Sydney and on the interstate tracks. Other jurisdictions will need to undertake this task prior to installing advanced train protection and control systems (not likely before 2017).

We have estimated that the ATMS system described above will have been introduced on the ARTC network by 2020. There will be advantages in capacity (more trains on a given track, hence postponement of investment in new infrastructure), reliability (hence stronger competition with other modes) and safety, as well as substantial cost savings in not having to maintain a traditional signal system.

3.3 In-cab signalling – productivity estimate

The ATMS in-cab signalling system would improve the efficiency of long distance train operation, eliminate expenditure on signal inspections, maintenance and renewal, and allow some investments in increased infrastructure capacity (e.g. extra lines or passing loops) to be deferred. The cost of ATMS would be significantly lower than the costs saved.

Augmented GNSS could be an enabling service for ATMS providing greater accuracy but, as mentioned above, high levels of reliability of position information. One area where augmented GNSS cannot at the present time provide such service is in tunnels. However the development of localised non-satellite dependent positioning technology that is compatible with GNSS signals offers some promise of a solution to this problem (see discussion in section 2.1.2 above).

No study has been published on the estimated size of the benefits a rough estimate based on partial industry information and ACIL Allen assumptions is a productivity improvement of 5% (high scenario) and 2% (low scenario). This would apply to approximately 25% of the rail sector, being the part controlled by the ARTC (interstate and Hunter Valley lines) – hence an average productivity improvement for the sector or 1.25% (high) and 0.5% (low). This does not allow for safety or reliability benefits, nor for longer term operational improvements made possible by the new technology.

ETCS (especially more advanced versions of the European system) would have similar improvements for urban railways, but they are not included as the European technology is not dependent on GNSS.

4 Productivity and economic impacts

Evidence from case studies and on levels of adoption were first used to estimate the potential impact on productivity and cost savings in the rail sector as at 2012 and the potential in 2020. These estimates were then used with estimates from other sectors to calculate the economy wide impacts of precise positioning for Australia as a whole.

4.1 Direct productivity impacts in the rail sector

The estimates of cost savings from the ATMS installed by ARTC and as discussed in Section 3.33.3 are shown in Table 1. ATMS can theoretically operate with signalling infrastructure and track circuits it could be more efficiently provided by augmented GNSS if it were available. Augmented GNSS is of course used in surveying track.

The table shows accumulated benefits in lower costs of between $1.8 million and $3.4 million in 2012 attributable to the use of precise GNSS in surveying track and rail infrastructure. This rises to benefits of between $9.5 million and $10.1 million by 2020 based on installation of ATMS on ARTC lines by 2020. The high case includes ARTC using Augmented GNSS also on dedicated mining rail lines.

Benefits in 2020 would be significantly higher if the metropolitan rail authorities adopted augmented GNSS for train control and monitoring. However as discussed in this report, the metropolitan authorities appear to be locked in to alternative approaches under the European ETCS technologies.

Table 1 **Estimate of benefits and productivity improvement in the rail sector**

	Description	Impact on costs	Percentage of value of production in sector	Impact on costs	Percentage of value of production in sector
		Low case	Low case	High case	High case
2012					
Precise GNSS use in surveying track and locating infrastructure	Estimate based on use of precise positioning in surveying rail track. Assumes 0.1% productivity with 20 % adoption for the low case and 0.15 per cent productivity improvement and 25% adoption for the high case.	$1,816,514	0.015%	$3,405,964	0.028%
2020					
Automated train management system for ARTC and dedicated mining industry infrastructure	Estimate based on assumption that ARTC ATMS achieves 0.3 % productivity improvement on its long distance lines . ARTC assets equivalent to 35 % adoption across the rail sector.	$9,536,700	0.080%	$10,081,654	0.084%

Note: Based on case study of ARTC ATMS and assumptions on adoption discussed in the text

Data source: ACIL Allen

4.2 Impact on sector output

The productivity impacts summarised in **Error! Reference source not found.** were used as inputs to ACIL Allen's Computable General Equilibrium (CGE) model, Tasman Global[2], to estimate the impact that productivity improvements from the use of augmented GNSS has had on the Australian economy in 2012 and the potential benefits that could arise by 2020[3].

The results from this modelling for output of rail sector are shown in Table 2.

Table 2 **Impacts on output**

		Low case	High case	Low case	High case
		2012	**2012**	**2020**	**2020**
Increase in output	$ million	1	3	10	12
Percentage of total output		0.1%	0.2%	0.3%	0.5%

Note:

Data source: ACIL Allen modelling

The results for 2012 are not significant reflecting only the impact of augmented GNSS on track surveying.

The results for 2020 are more significant reflecting in part the benefits of ATMS for used in long distance rail operations. These results suggest that

[2] See overview report for a full description of the CGE modelling approach,

[3] Note that the productivity shocks for other sectors discussed in this report were also entered into the model at the same time.

output in the sector could be up to $12 million higher than it might otherwise be without greater use of the technology. This still only represents around 0.1 per cent of the output of the rail sector as a whole.

These results could be higher if metropolitan systems adopted ATMS systems. However to utilise augmented GNSS, there would need to be further development of localised GNSS compatible positioning systems for use in tunnels. There is no technology currently available to do this task.

Appendix A Case studies

A.1 RailCorp (Sydney Rail)

RailCorp uses high resolution GNSS for surveying track, and benefits from the efficiencies created by high resolution positioning. Accurate location and time-stamping of GNSS data are important where the RailCorp test trains are recording images of line side track infrastructure.

RailCorp has opted for ETCS as its train protection and control system. This system uses balises mounted between railway tracks to provide location information and movement authorities. Low-resolution GPS sensors are fitted on most trains. This will be used for backup and verification purposes, as well as asset location.

Apart from surveying for track maintenance, there are few benefits to high resolution GNSS in train operations on RailCorp's passenger networks.

A.1.1 Background

The ETCS integration manager at RailCorp (soon to be Sydney Trains) was interviewed.

RailCorp is investing in improved train safety systems. RailCorp has opted to purchase an established system called European Train Control Systems (ETCS). There are different levels of ETCS and RailCorp is opting for the lowest level – Level 1 with an option to upgrade to the more beneficial ETCS Level 2 in the future.

ETCS Level 1 links to existing signalling systems, and train positioning and movement authorities are relayed to an on-board computer and then to the drivers in-cab systems as trains pass over transponders or 'balises' mounted between the tracks. The on-board computer continuously monitors and calculates the maximum speed and the braking curve from these data. Because of the spot transmission of data, the train must travel over the balise beacon to obtain the next movement authority.

ETCS improves safety because it does not allow a train to pass a signal at danger. Balises are placed at locations that will allow sufficient braking distance as the train approaches the signal. Between two balises the train continues to determine its position via sensors (axle transducers, accelerometer, etc.). ETCS Level 1 provides some additional track capacity because clearances are not required beyond signals – at the moment some track is kept clear after a signal in case a train overruns it – in the case of junctions this can impact network capacity significantly. ETCS Level 1 means this overlap is no longer required.

ETCS Level 2 is a digital radio-based signal and train protection system. Movement authority and other signal aspects are displayed on the in-cab systems to the driver. It is therefore possible to dispense with trackside signalling. All trains automatically report their exact position and direction of travel to the Radio Block Centre (RBC) at regular intervals. Train movements are monitored continually by the radio block centre. The movement authority is transmitted to the vehicle continuously via GSM-R together with speed information and route data. As with ETCS Level 1, the balises are used as passive positioning beacons. Between two positioning beacons the train continues to determine its position via sensors and the positioning beacons are used in this case as reference points for correcting distance measurement errors. The on-board computer continuously monitors the transferred data and the maximum permissible speed.

ETCS is an old technology developed before accurate GPS was widely and cost-effectively available. It is, however an established technology with multiple suppliers and it is relatively cheap. There seems to be no intention to replace balises as the positioning device. Balises need to be placed on the track, and the ability to have short headways depends on the distance between balises. These balises need checking, maintenance and renewal over time. They are clearly a technology more suitable for urban networks with many signals over hundreds of kilometres of track, but they are less suitable for long-distance running and single line track, as in the case of ARTC (above).

A.1.2 ETCS use of high resolution positioning

In order to implement ETCS the position of track, signals, and the placement of balises needs to be known exactly. The ETCS design needs to know the location of signals, limits of authority and the centre line of the train. The required accuracy is within 1 metre. For this purpose RailCorp is surveying its existing track. New track installations are already recorded to very high levels of accuracy (thanks in part to modern GPS use), but older sections of track were recorded with less precision and a program is underway to rectify this.

For the surveying of track RailCorp is now using Oxford Technologies inertial navigation boxes mounted on test trains (these are GPS-integrated Inertial Measurement Units or IMUs). They need the IMUs because of passage through tunnels. The inertial positioning equipment also calculates the gradient with more accuracy than the GPS. RailCorp use Omnistar XP for precise GPS positioning – this is because the Oxford Technologies box can use Omnistar data. The average accuracy is within 15cm. 2-3 runs of recording are undertaken to verify measurements.

The track surveying project is expected to take 10 years to complete. It is starting from the edge of the network, moving in to the centre of the city. RailCorp already has a dedicated site surveying team who can measure to within 1cm accuracy. This team is usually dispatched to new site installations. They cost the company some $16 million per annum.

If RailCorp were not using Omnistar they would have to use traditional surveying methods, which would require much more labour, manual inputting and with greater error rates.

The application of ETCS requires significant investment. For the survey RailCorp is using electric test trains fitted with ATP equipment, GPS antennae and GPS inertial measurement units (IMUs). The IMUs cost some $60,000 with an additional $10,000 to fit them.

These trains take line scan pictures at 1,000 lines per second from the side of the train, building up a precise 3-D picture of the track and trackside assets. This is mapped to GNSS locations within 1cm accuracy. Accurate recording of GNSS timestamp is necessary to align the pictures to the location. These cameras cost $2,000-3,000 each.

A.1.3 GNSS uses in maintenance

RailCorp has commissioned 3 new track-recording vehicles which will do weekly surveys of top, twist, gauge, damaged track, and other maintenance tests. Typically these do not need high resolution GNSS as maintenance crews can locate the issues when given locational coordinates within a few metres. The track-recording vehicles will use survey geometry for baseline which is within 2cm of accuracy.

A.1.4 Other GNSS uses at RailCorp

Country trains in NSW and Waratahs in Sydney have GPS locators fitted on them for information on train location, but there is little need for accuracy. The country lines are not heavily trafficked.

Passenger information in Sydney displays pick up train location information based on track circuits/signalling infrastructure. Hence, the time until the arrival of the next train is measured as a standard time from the last occupied track section. GPS could be used for this, but adds little benefit.

A.2 Rio Tinto Iron Ore - Rail

Rio Tinto manages about 1,700 kilometres of track. There are 150 locomotives, including 8 maintenance vehicles, 8 bankers and 35 trains with 240 wagons per train. About 10 locomotives per year are being added to deal with volume growth. Train lengths are typically 3 kilometres long. Train lengths up to 7 kilometres have been seen in the Pilbara. Trains operate with 20-25 minutes headway. There is 200-300 kilometres of dual track at the most congested sections (typically the approach to port).

There are a number of useful GNSS applications, but none require high precision GNSS.

Train location is currently determined using signalling infrastructure and track circuits. Ultimately, this is nineteenth century technology[4]. The information that is gathered by this system is that it took several minutes for a train to clear a certain section of line. If the train encounters a delay it is not known where on the line segment this happens. More recently GNSS recording of the journey has provided additional useful data.

Rio Tinto trains use Automatic Train Protection (ATP). In July 2012 Ansaldo STS Australia was awarded a A$317 million contract to develop and deliver an automated train management system for Rio Tinto's iron ore rail network in Western Australia. The ATP system is expected to be finalized in 2015, and is intended to improve flexibility and capacity on Rio Tinto Iron Ore's mining rail network, it is likely to include GNSS. When the signalling system is implemented, Rio Tinto will be able to use driverless trains to transport iron ore on its 1,700km rail network in the Pilbara region.

A.2.1 GNSS application by Rio Tinto

GNSS is used to monitor the progress of trains between mines and port to improve asset efficiency and planning. Rio Tinto now uses GPS records of train movement to map the journeys and record delays and bottlenecks.

The past system was based driver recall – where he has to log any delays after a journey is completed. The recall method was performed by train control showing the driver a record of their train graphs and asking the driver to explain delays – this system caused a number of disputes between drivers and train controllers. GNSS records are considered more reliable and eliminate disagreements.

GNSS is also used to track assets. Rio Tinto records the turnaround time for assets, so timing the time taken to unload a payload, move to the yard, refuel, perform maintenance checks, return to a mine, load, and return to port. Minimising non-productive time is key to efficient asset use.

Sometimes locomotives are left in the yard and forgotten about. Given that each locomotive costs $3-$7 million this is an expensive waste of assets. By recording the location and movement of assets Rio Tinto hopes to optimise their utilisation.

Standard GPS doesn't identify location very well in the yard because of bounce off the metal structures. Differential GPS would fix this. The cost to implement high resolution GPS in the past has been prohibitive – 'Blackbox' pricing was $3,300 per annum per locomotive plus operating costs. With 140-150 locomotives this was approximately $0.5 million per annum more than standards GPS for little gain. Rio Tinto is adding some 10 locomotives per annum to its fleet so this cost would escalate.

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[4] The failsafe track circuit was invented in 1872 by William Robinson

When recording the movement of locomotives in transit location information is sent every 5 minutes. This is sufficient for asset management purposes. The first time that Rio undertook this exercise they sent information from 50 locomotives much more frequently and its first bill was in excess of $1 million.

Rio experienced some issues arising from inconsistent time stamps on stand-alone GNSS data. A frustration is that sometimes there are no GNSS changes and the train appears stationary, then there is a jump in location when all the data arrive at once. Precise positioning GNSS would address this problem.

A.2.2 Other GNSS uses

Rio Tinto is incorporating driverless trains and also fuel-saving software. These will both use GNSS locational information, but again will not require high resolution positioning.

Although not identified by Vanessa during the interview, it is possible that more advanced train protection and control applications may, in the future, require high-precision records of the location of track and signals.

A.2.3 Conclusion

The key issue for Rio Tinto was the cost of GNSS data. High frequency and high-precision uses were not taken up by Rio Tinto because of cost. In the mines there are applications of high-resolution positioning, but they are less important in the rail side of the business, which works on simple rail networks and very long trains.

If augmented GNSS were used it could be used for time stamping of train location as part of an ATMS. However our advice was that this alone is not likely to be sufficient justification for use of augmented GNSS.

A.3 Asciano

The Manager of Strategy and Infrastructure Planning at Asciano identified a number of GNSS uses in Asciano, and the benefits from GNSS use. In Asciano's rail operations there were no requirements for high-precision GNSS at this time. The overriding concern was integrity.

A.3.1 GNSS use in terminals

Asciano uses high-precision GPS in automated stevedoring through its Patrick subsidiary located at Port Botany. Precision is required to the millimetre and GNSS is augmented by radar positioning. Had high-precision GNSS been available ten years ago perhaps this would be the sole positioning system in use. Port case studies have been discussed in the associated transport report.

Asciano operates rail line haul and terminal operations. The terminal operations could conceivably be automated in the long run, but they are more messy than port stevedoring. At ports there are fenced off areas where personnel are not allowed to enter. In terminals there are trucks arriving late with containers, and so more judgement is required in loading the train. The movement of trucks makes the set-up more fluid than stevedoring operations.

Trains are also loaded to a complex plan with rules for dangerous goods, refrigerated containers, double stacking (heavier boxes and boxes with a minimum structural integrity on the bottom).

Asciano uses GNSS to monitor the movement of train loaders (fork lift trucks). This is used to determine whether train loaders are taking efficient routes to load the train or whether they are making excessive movements up and down the train.

A.3.2 GNSS use in fuel economy software

The difference in fuel use between Asciano's best and worst drivers (from a fuel economy point of view) can be significant. A key requirement for optimised fuel consumption is to minimise the acceleration and to minimise braking by using the natural topography. This approach is been applied in road freight in Europe using the European Geostationary Navigation Overlay Service (EGNOS)[5]. This is not an easy task when the driver has three locomotives pulling 1200-1700 metres of trailing wagons carrying thousands of tonnes of goods.

Software such as 'Leader' and 'Freightmiser' has been developed to optimise the train speed and acceleration based on a digital map of the route including gradients and curves, the location of signals and the location of the locomotives as well as incorporating information on the consist that the locomotives are pulling and the time at which the goods need to arrive.

Typically these systems provide recommended speeds and acceleration/braking advice to drivers on an in-cab display, they require positional information and the more accurate this is, the better the advice that they can provide to drivers.

The accuracy of the information needs to be within 100 metres of actual position. The integrity of the system is not vital because this is not a safety system – it improves the efficiency of the journey.

Freightmiser's marketing material indicates that a 10% increase in fuel efficiency could lead to a $100,000 saving per locomotive per annum (dependent on fuel price assumptions, operation between Melbourne and Perth and whether this fuel saving would, on average, be achieved).

Freightmiser is used by Asciano on its east-west route, but will eventually be rolled out to all intermodal and bulk haulage operations. Asciano's intermodal

[5] EGNOS is a Space Based Augmentation System (SBAS). EGNOS and Galileo are now part of Europe's GNSS programmes managed by the European Commission.

fleet is 350 locomotives. This could generate savings of $35 million per annum. If the same benefits accrued to QR National's and SCT's fleet then the national savings could be in the order of $5 million per annum. There would also be significant benefits in the use of this software in mining rail applications.

A.4 Productivity impacts – high resolution positioning

This section assesses the productivity impacts of high resolution positioning in the rail sector. They are relatively minor compared with the impact of in-cab signalling (which does not require high resolution) discussed in the main body of the paper, and are not included in the overall productivity estimate.

A.4.1 RailCorp and ARTC's use of high resolution GNSS

High resolution GNSS is used in surveying applications. This is covered in a specific case study on surveying, and to separately include this as a productivity impact in the rail sector is likely to lead to double counting.

In the case of ARTC and RailCorp high-resolution surveying would create a significant cost saving from avoiding the need to re-survey to resolve discrepancies.

A.4.2 Improving the efficiency of train loading

Precise positioning is not needed to monitor the movement of fork-lift drivers when loading trains, although vertical positioning accuracy and high levels of integrity would be beneficial. There are no gains expected from high-resolution positioning for general train loading. This differs to some extent to the use of augmented GNSS in locating and managing containers operations at ports.

A.4.3 Improving the efficiency of locomotive use in the mines

High resolution GNSS is generally not needed to locate locomotives in yards as the locomotives are under close supervision by operators. If it were to be used in shunting yards it would require augmentation to avoid errors introduced by signal bounce from the steel structures surrounding the locomotives.

It could be used for better management of assets en route. If asset location can increase the average use of assets by, say, 5% then at a new asset value of $5 million, instead of 10 new locomotives every year (20 every two years), then perhaps only 19 new locomotives would be needed every two years. This would save an ongoing cost of roughly $2.5 million per annum. There would also be a one-off benefit of a 5% efficiency gain on the fleet of 150 locomotives – if the average asset value is assumed to be $4 million then 5% additional productivity could be valued at $30 million to Rio Tinto.

Similar (indeed, larger) gains could be obtained at BHP Billiton facilities. Again, it is unlikely that high resolution services would be necessary.

A.4.4 Improving the performance of driver optimisation software

If improved resolution and higher integrity GNSS could improve the efficiency of Freightmiser by 1% then this would create estimated benefits of up to $350,000 per annum to Asciano.

If the same benefits accrued to QR National's and SCT's fleet then the national savings could be some $0.5 million per annum. There would also be similar scales of gain to mining companies who run their own trains on their lines.

This would also reduce greenhouse gas emissions from rail transport by approximately 0.1%.

Appendix B Acronyms

Acronym	Meaning
ATMS	Automated Train Management System
ATP	Automatic Train Protection
ATRC	Australian Rail Track Corporation
ETCS	European Train Control System
GNSS	Global Satellite Navigation Systems
GPS	Global Positioning System
IMU	Inertial Measurement Units
PNT	Positional, navigational and timing
RBC	Radio Block Centre

Appendix C References

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